Assessing the Effects of Shallow Coals and Reclaimed Mine Lands on Soil Gas Geochemistry

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Acknowledgements:
Kentucky Office of Energy Policy, UK Arboretum,
UK Robinson Forest, UK Environmental Research and Teaching Laboratory,
Bretagne Oil Company, Interstate Natural Gas, Trinity Coal Company,
Many Surface Land Owners, Ron Klusman

I. Objectives

- Characterize soil gas flux and composition in surface and near surface environment (< 10 m) in areas overlying or near possible carbon sequestration sites in eastern Kentucky.
- Identify and quantify variations in soil gas flux and composition resulting from biologic, atmospheric, and geologic inputs (i.e. microseepage).
- Identify basin-specific factors contributing to soil gas anomalies and how those factors impact soil gas chemistry as a Monitoring, Mitigation, and Verification (MMV) tool.

Hence, the focus point of this presentation: the effects of reclaimed mine materials and shallow coal beds on soil gas chemistry and flux.

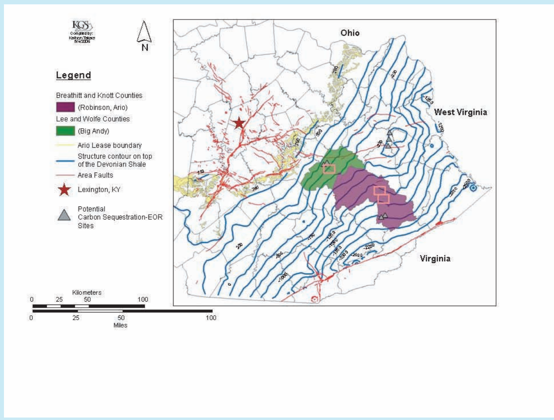

Figure 1- Study sites in eastern Kentucky.

II. Surface and Shallow Soil Gas Methods

- Winter and summer 2006-soil gas flux (CO_2, CH_4); and soil gas (< 100 cm) and atmospheric composition (CO_2, CH_4, delta^{13}C-CO_2) measured at 28 locations distributed among a research forest (UK Robinson), an active gas field (Ario), and an active oil field (Big Andy) undergoing limited enhanced oil recovery with CO_2 and N_2 (Figure 1).
- CO_2 and CH_4 concentrations of soil gas samples (30, 60, 100 cm), atmospheric, and chamber samples measured using GC methods.
- Stable isotopes (del^{13}C, del^{18}O) for soil gas and atmospheric CO_2 measured wtih mass spectrometry methods.
- CO_2 fluxes measured with Licor LI-8100 infrared analyzer equipped with 20 cm survey chamber (Figure 2). CH_4 fluxes calculated based on changes in chamber CH_4 concentrations with time (Klusman, 2003).
- Triplicate flux, duplicate soil gas, and single atmospheric measurements made at each location.

Figure 2- Field infrared analyzer with soil collars fitted with sampling septum.

III. Results

Winter and summer measurements provide a heretofore absent soil gas database that will be an integral part of future MMV analyses. Highlights are:

- Positive CO_2 fluxes measured at all locations, and summer flux magnitudes (avg.= 15.7±6.2 grams/m^2/day, n= 84) > winter (avg.= 4.6±0.77 grams/m^2/day, n= 83).
- Winter and summer soil gas CO_2 concentrations > atmospheric, and provide driving force for positive flux (Figure 3).
- Most chamber CH_4 concentrations showed no consistent increase or decrease with time for a given location (65%, n= 106). A smaller number showed negative fluxes (28%, n= 46), with average flux equal to -1.69±1.5 grams/m^2/day. A yet smaller showed positive fluxes (7%, n= 11) with average flux equal to 1.31±1.4 grams/m^2/day.
- Soil gas CH_4 concentrations slightly less than atmospheric and small difference accounts for subtle negative flux and difficulty in measuring flux at some locations (Figure 4).
- Greater than 90% soil gas CO_2 samples (n= 329) have del^{13}C values depleted in ^{13}C relative to atmospheric CO_2, and fall along mixing line defined by atmospheric and 100 cm averages, with latter being a proxy for soil organic matter (Figure 5). Depleted del^{13}C values and placement of most samples near the 100 cm anchor point suggests soil gas composition is primarily influenced by soil microbial activity with smaller atmospheric contributions. Subsequent discussion will demonstrate that shallow coals could also be a contributor.

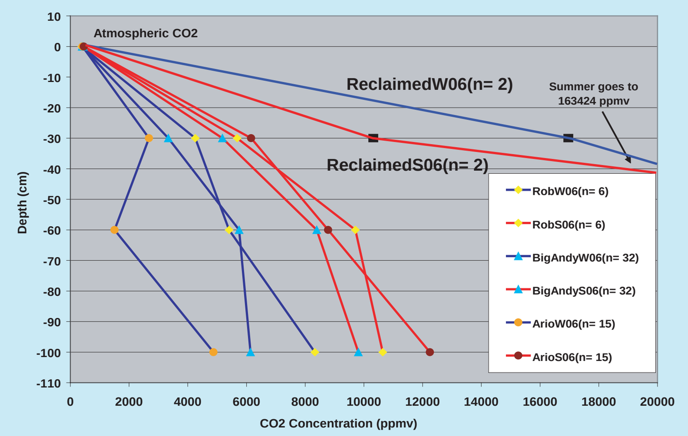

Figure 3- Soil profiles showing average CO_2 concentration. Red and blue profiles equal summer and winter measurements, respectively.

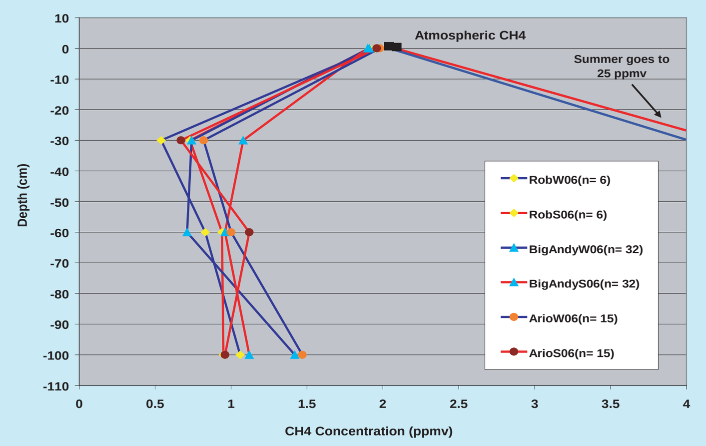

Figure 4- Soil profiles showing average CH_4 concentration. Red and blue profiles equal summer and winter measurements, respectively.

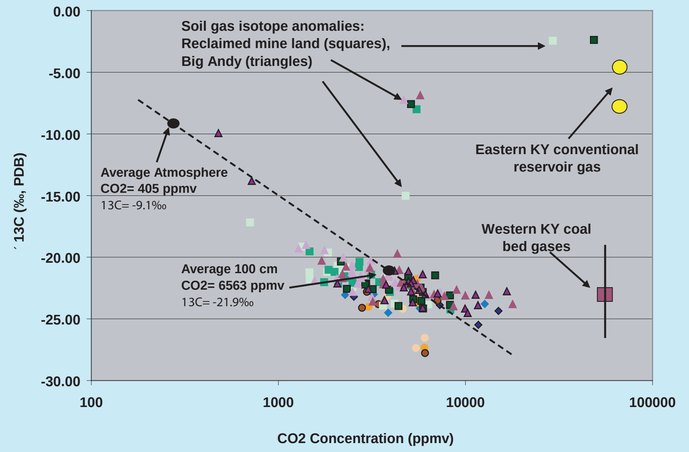

Figure 5- Winter soil gas CO_2 composition. Yellow circles--CO_2 isotopic composition from natural gas samples from Cambro-Ordovician reservoirs (Harris et al, 2004). Red square--average CO_2 isotopic composition of Pennsylvanian western KY coal gas (Strapoc et al., 2007). Position of natural and coal gas samples in plot denotes isotopic composition and not CO_2 concentration.

IV. Defining Soil Gas Anomalies

- Geologic, cultural, and soil gas data used to define soil gas anomalies.
- Emphasis given to locations having positive CH_4 fluxes, soil gas CH_4 concentrations > atmospheric CH_4, or enriched del^{13}C-CO_2 values relative to atmospheric- deep soil gas mixing line (Figure 5).
- Defined 7 significant anomalies coincident with cultural disturbances (2), Rome Trough and associated faults (3), reclaimed mine land (1), and location with no clear causal mechanism.

V. Reclaimed Mine Land Soil Geochemistry

- Highest soil gas CH_4 and CO_2 concentrations (Figures 3, 4).
- But, relatively low CO_2 and CH_4 fluxes.
- Some of most isotopically enriched soil gas CO_2 (Figure 5).
- Anomalies likely due to: (a) Abundant coal fragments in surface cover (Figure 6), (b) buffering reactions with carbonate cement in siliciclastic clasts (Wunsch et al. 1996), and (c) heavily compacted surface cover and low permeability.

From MMV perspective, reclaimed mine anomalies are significant because:

- Enriched del^{13}C-CO_2 values are similar to del^{13}C-CO_2 values for natural gases in conventional eastern KY reservoirs (Figure 5).
- GIS analysis by author Takacs shows that some of the most prospective oil/gas fields for sequestration-EOR projects (includes KY FutureGen site) in KY have or had surface mining activity; up to 18% of pool area in some cases (Figure 1).
- Similar soil gas criteria have been used elsewhere to define microseepage anomalies related to gas migration along faults and enhanced oil recovery activity (Klusman 2003, 2006).

Reclaimed mine land anomaly thus provides a false positive of conventional microseepage!

VI. Potential Shallow Coal MMV Issues

- Study area and many prospective KY geologic sequestration targets are underlain by shallow coals (Figure 1).
- No data available for eastern KY, but del^{13}C-CO_2 values for Pennsylvanian western KY coal gases similar to soil gas composition (Figure 5), which complicates ability to decipher biologic signal.
- Western KY coals have ethane and propane concentrations up to 7.8% and 3.0%, respectively, and elevated concentrations of these gases have been used as evidence for microseepage (Klusman, 2003).
- Similar maceral composition between eastern and western KY coals suggests similar gas composition.
- Low permeability and propensity to adsorb CO_2 might impede upward migration of CO_2 gas thereby reducing efficacy of surface and near-surface monitoring (Oldenburg and Unger 2003). Effect potentially offset by cleats and relaxation fractures.

VII. Summary and Future Studies

- Similar del^{13}C-CO_2 composition between eastern KY conventional gas and enriched soil gas at the reclaimed mine location suggests that shifts to enriched del^{13}C-CO_2 values might not be effective in detecting microseepage in such settings.
- Soil gas del^{13}C-CO_2 composition is similar to that for coal gas in this study, and similarity complicates resolving biologic and geologic inputs to soil gas composition. Indeed, similarity might signify that shallow coals, despite the presumption of being degassed, continue to influence soil gas composition.
- Above issues underscore need to fully characterize surface and near-surface geologic setting in which MMV analyses are conducted. In some settings, it may be necessary to further analyze gas species, in addition to CO_2, in order to fully characterize potential reservoir contributors to microseepage.
- Future work will characterize hydrocarbon gases (methane, ethane, propane) in effort to discriminate sources influencing soil gas composition (Figures 7, 8). Work will be done with current surface investigations and deep soil gas wells located in areas of soil gas anomalies.
- Deep soil gas wells (Figure 9), will be configured to analyze gases at systematic depths to ~10 meters, and to test the influence of shallow coals on vadoze zone transport using injected tracers (e.g. Wells et al. 2006).

Figure 6--(a) anomalous reclaimed mine site. (b) Surface covers includes unsorted mixture of coal (dark clasts) and siliciclastic material (tan and gray clasts). Chamber diameter is 20 cm.

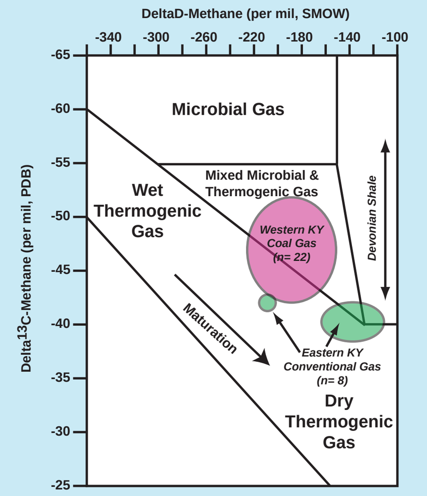

Figure 7- Schoell (1983) diagram showing isotopic variation of some Kentucky natural gases.

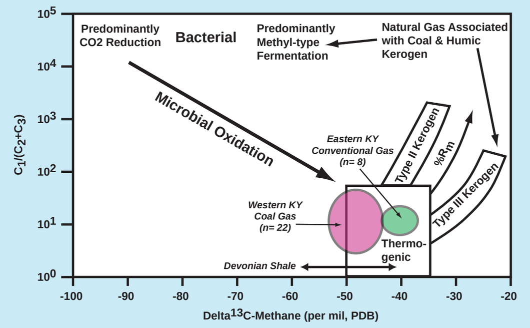

Figure 8- Bernard style diagram used to discriminate gases of different origins, but modified by mixing and oxidation (Whiticar 1996).

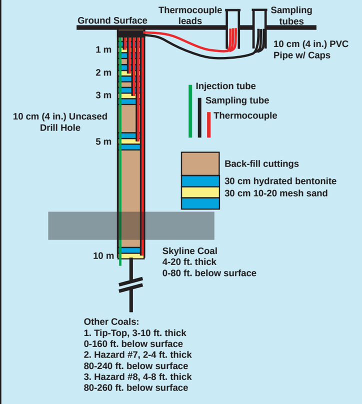

Figure 9- Schematic diagram of deep soil gas well that will further investigate soil gas chemistry in the area of 3 or 4 soil gas anomalies distributed among the study sites, and to test the influence of shallow coals on vadose zone gas transport.